PETRIFIED SUNLIGHT

By G. B. MATHEWS

"Of Lice and Men," Dr. Mathews' article on the fight against typhus which was published in our issue of March 1943, found much acclaim among our readers. In the following article the author again reveals his talent for presenting an involved topic in a manner comprehensible and attractive to the layman. The reader follows him through the different processes by which sunlight was stored up for posterity's use aeons ago in the depths of the earth and realizes the myriad uses to which the modern world has put this product of the dim past.—K.M.

COAL has been defined as a sedimentary rock of phytogenic origin of varying geological age. It can be used for burning and should not have more than 50 per cent ashes after combustion. This description, arbitrary though it is, serves its technical, industrial, and commercial purpose and reveals its practical standpoint at the time of its coining. The merchant looks at the burning qualities of coal; the industrialist at the production qualities—gas, tar, etc.; the navy at the smoke, etc.; the chemist at the amount and quality of ulmin constituents, the reactivity index as a measure of oxidation; whereas the geobiological expert regards coal from the standpoint of its age and its organic constituents, such as ulmic substances, algae, spores, which serve as an index for classification.

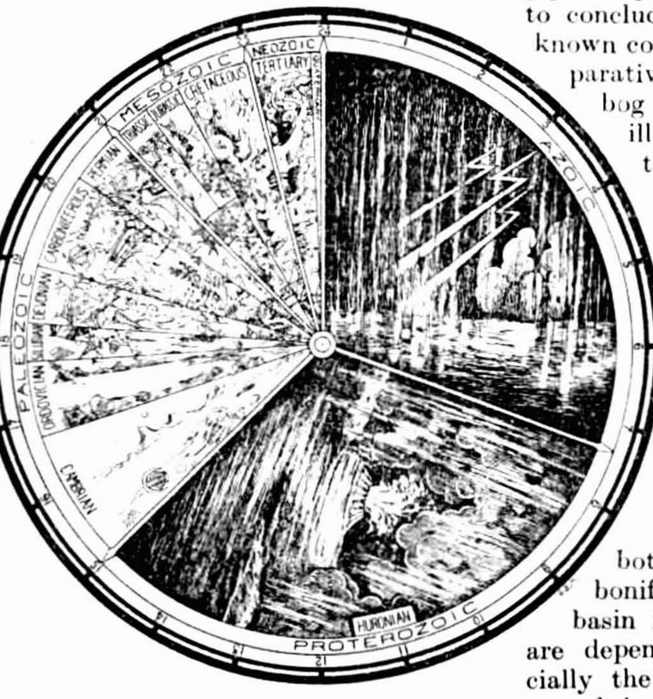
Where does coal come from, and what agencies, biological, chemical, etc., are responsible for coal-formation? What materials contributed to the making of the black diamond; what climate featured in its formation; when and how many million years ago was coal brought into being; what stages did it go through before it was ready to heat our stoves, give color to our clothes, and lessen our pains in illness?

Coal is an accumulation of plant remains of former ages. Many factors play determining roles in the manufacturing processes of coal, as we shall see later. We must bear in mind that the carbon of the plants, and hence of the coal, is not obtained from the soil by way of their roots but from the air by way of their leaves. Consequently, the original source of the vast amount of carbon locked up in the great coal fields was the carbon dioxide that formed part of the atmosphere in the coal-making era. The potential energy present in coal is the energy of the sun stored since time immemorial when the plants that now constitute coal were alive and green and capable of storing the radiant energy of the sun and transmitting it in a latent form to our era as petrified sunlight. Coal may be called "bottled sunlight," which is as substantially correct a name for it as it may sound fanciful.

WHEN WAS IT FORMED?

Coal was formed at different times during the geological periods. The coal age or coal measures were chiefly at the close of the Paleozoic, in the Carboniferous, when coal seams were laid down in North China, Northern Europe, and North America. Coal was also formed in the Jurassic, Cretaceous, and even in the Tertiary periods. How far back do you think these periods lie? A fairly accurate measurement for the length of time is the disintegration of radium, which is very regular and cannot be influenced by any of the known agencies.

It may help us to study the geological clock in order to locate each period in its proper place. The long span of time since our planet became more and more solid is divided into twenty-four hours. Each hour is equivalent to 60 million years. The time which elapsed since the coal-formation during the Paleozoic period has been measured—and that quite accurately—to extend over one hundred million years, including the Carboniferous and part of the Permian.



GEOLOGICAL CLOCK

Illustration shows the time which has elapsed since the solidification of the earth's crust. One hour of the clock equals approximately 60,000,000 years. Man appeared in the Quaternary, the last minute, assuming that the Quaternary has lasted more or less a million years, as is generally accepted.

If we examine a lump of coal, it is usually difficult to discern with the naked eye any structure or material which would hint at the nature of the black sooty material. In the coal mine, however, it is an easy matter to look at the fire clay below the coal seam and to make out the impressions of roots and stems of plants, herbaceous and woody. Likewise, in the roof of the seam, impressions of leaves, stems, and fructifications can be recognized in the sandstone or shale (compressed mud). Microscopic investigation of a lump of coal shows the detailed anatomy of the plant part; chemical analysis reveals to us the hydrocarbons stored up since the plant died. Thus what the miner brings up from the depths of the earth is really sunlight wrapped up in the black gloomy mass.

What does our study tell us about the plants which made up the coal forests? The forests of that time were swamps of gigantic proportions, as we are permitted to conclude from the extensions of the known coal fields (see Map A). A comparative study of a present-day peat bog and a coal field gives some illuminating views of the formation of coal. Aeons before the sable-toothed tiger was fought by *Sinanthropus*, millions of years before the giant dinosaurs wallowed in the mud of the Shantung plains, immense swamps covered the districts where we now find T'ang-Shan, Tatung, T'ai-Yuan, etc.

THE PLANTS WHICH CONTRIBUTED TO COAL

For our knowledge of the botanical character of the Carboniferous flora, e.g., of the Kaiping basin in the province of Hopei, we are dependent on fossil remains, especially the casts and impressions preserved in the layers of shale or sandstone which separate and cover the coal beds. The plant remains themselves in the coal seams have for the most part been so greatly compressed and modified that individual parts are not readily distinguishable. The fossil remains, however, are numerous. They abound on the mine dumps in all coal areas. Unfortunately, they are always fragmentary; but, thanks to the painstaking and industrious study of paleobotanists the world over, there are now sufficient data available concerning the plants as well as animals, insects, and vertebrata including primitive fishes and feeble-limbed reptiles. Thus we arrive at a fairly definite conception of the general constitution of the flora of the coal forests.

We even learn a great deal about the anatomy of the many plants of that time, about the cellular composition, the arrangement of the tissues, their fructifications, size and arrangement of spores. This knowledge, so essential to the classification and establishment of relationship to modern plants, is gained from coal-balls. Coal-balls, in the paleobotanical sense of the word, are concretions which are found in coal containing petrified plant remains. By means of thin sections or peels, the cellular structure of a plant can be determined. Coal-balls have not yet been found in East Asia or India, but it is merely a matter of time and search until the discovery of these very important documents of the coal-forest archives.

In these archives, where all documents are written in stone, we find representatives of plant families still extant today, though quite changed in habit and size. We recognize ancestors of our pine trees and wonder about the specimens which have no relatives today. The flora known to us—and there is little hope that our knowledge will be considerably enlarged—is that of a swamp forest. On the whole, the forests were monotonous and uniform. In a restoration we usually group together all the specimens of plants known to have existed over a wide area or in different coal seams. As a matter of fact, one coal seam may have only one or two kinds of plants which covered large tracts of land, near shallow water or at the back of a large watercourse, a locality where stagnation rather than movement prevailed.

The T'ang-shan flora was a kind that flourished only in the presence of abundant moisture and equable climatic conditions the year round. The borders of the estuaries were lined with calamite rushes, a treelike relative of our horsetails. They approached bamboos in height, though their diameter was even larger. The large horsetail rushes were greatly exceeded in size by the trees that formed

MAP A

Map of the world today showing the distribution of the northern coal fields (shaded areas) along the theoretical equator of the Carboniferous period (E.C.)

The dotted areas indicate the extent of the southern *Glossopteris* flora, named after the most prevalent genus, *Glossopteris*.

the bulk of the vegetation. The two principal types of these specific Carboniferous trees were the *Lepidodendron* and *Sigillaria*. These huge club mosses, with their columnar trunks, fluted or ornamented as if by sculptural pattern, with their sparse or branchless tops, must have set a somber stamp on the entire landscape. The branches bore pendulous cones of enormous size, as large as 70 centimeters across. It is not surprising that the prodigious amount of spores produced and shed made up an important element of the plant material that was converted into coal. In fact some seams of coal seem to have been made entirely from spores. Of these two groups, only dwarf relatives exist today, viz., the ground pines and the selaginellas.

Another extensive group of tall trees were early gymnosperms, the *Cordaites*. These trees attained or even exceeded heights of 30 meters with a diameter of no more than 50 centimeters. The long straplike leathery leaves can be found all over the world. It has been suggested that these trees grew on the uplands and that their leaves and seeds may have drifted down the streams and were buried and preserved while the tree trunks themselves died and decayed on the uplands. Of these *Cordaites* as well as of other trees, only the inner casts of the stem core (pith cavities) have been preserved, making determination and classification immensely difficult. More than fourteen names have been given to the various parts of one single species of the *Lepidodendron* because its leaves, buds, roots, stems, branches, etc., were found separated, and at the time it was impossible to know the relationship of the detached parts. Later on, larger portions of the *Lepidodendron* were discovered and the original relationship was established.

The shade of the upper canopy of the branches and needlelike leaves was not dense enough to prevent a luxurious vegetation of lesser size during the Carboniferous era. Fossil records include an extraordinary quantity and variety of stems and leaves (fronds) of fernlike aspect. Some of these plants were climbers, as can be deduced from their long, slender, weak stems. One of the more numerous leaves found universally belongs to a straggling, slender, fragile herb bearing the external appearance of our bedstraw (*Galium*). In the Carboniferous era there is already evidence of smaller club mosses, tiny ferns, mosses, and liverworts. These must have constituted the ground cover in places favorable to their development. Fungi, parasitic on old tree trunks and fallen stems, have been found. They, as well as bacteria, undoubtedly brought about the disintegration of some portion of the enormous mass of vegetation litter of the forests.

By no means the least interesting feature of the Carboniferous forest is its animal life. Primitive four-footed vertebrates moved along over the ground and fallen stems. Some were tiny forms; others attained a length of three meters.

MAP B
The world during the Carboniferous period
All continents are united in one block. N and S indicate the positions of the poles. E.C.: equator at the Carboniferous period. E.P.: equator during the Permian period. C: coal deposits, close to the equator. The extent of the present-day *Glossopteris* flora is indicated by a dotted line around the Carboniferous south pole.

Besides fishes, reptiles, and amphibians, no other vertebrates, such as birds or mammals, roamed around. Insects were numerous. The modern groups, such as butterflies and beetles and bees, were entirely unrepresented; but some well-defined groups, such as the mantids, stone flies, and roaches, left their records in the stone. Compared to the modern types of insects, the primitive insects were large and rather clumsy and, on the whole, adapted to short flits and glides rather than flight. Dragon flies had a wing spread of 70 centimeters, and cockroaches were represented in hundreds of species. All the unmistakable peculiarities proper to this tribe today were already fixed in their ancestors of the Carboniferous forests. No one today can lay better claim to an ancient pedigree than the cockroach.

And all this life, strange if it were to appear today, was going on under a constant humid warm climate. We learn from the wood of the trees that there were no seasonal changes. Many years later, the coal forest was covered by water, mud, and sand. As the centuries swept by, a new forest grew up and flourished for thousands of years and was in turn buried under masses of sand. It has been calculated that one meter of coal seam represents 10 to 15 meters of peat. In some places we can still see several hundreds of such natural disasters, one after another, the several hundreds of coal seams varying in thickness from a few centimeters to several meters. This titanic drama went on for millions of years.

CONTINENTAL DRIFT

When you look at Map A, you may ask: if the climate was so uniform—as we rightly deduce from the fossil evidence—and the temperature was warm and humid, how then can the fact be explained that there are extensive coal fields in Northern Europe, Northern Asia, and North America, and that their floral composition is the same as in the latitude of, for example, Spitsbergen, where the polar nights last for several months? And how can the presence of coal or fern impressions in Greenland be explained? These curious facts are best explained by the theory of "continental drift."

This theory assumes that the continents, as we know them today, were not always fixed in their present position but were once part of one great single land mass which later split up into portions that gradually drifted apart. Map A indicates the general distribution of the two coal floras—the northern and the southern; Map B shows the approximate arrangement of the present-day continents as parts of the Paleozoic continental block. The poles are also indicated, showing that the northern coal forests thus came to occupy a position along the equator. This fact would account for the uniform climatic conditions and for the uniformity of the *Glossopteris* (southern) flora in the now dispersed southern continents. Although this theory has not met with unanimous approval by the geologists, nothing else so well explains the wide distribution of the Carboniferous plant deposits of the coal age.

HOW WAS COAL FORMED?

Having studied the botanical components of coal and the geographical distribution of coal beds, we shall now turn to the processes by which plant material is converted into coal. We begin with the biochemical processes. Plant material in bogs usually decays before coal-formation sets in. Decay may assume various forms, as can be deduced from the observation of peat bogs. The air (oxygen as the most active agent) may have free access to the plant material. Complete decay is effected by dissolving the material into simpler substances of gaseous liquid character, such as carbon dioxide and water. Thus no considerable amount of solid material to contribute to the formation of peat or humus would remain.

If, however, the access of air is checked, moldering takes place under moist conditions. This process can be observed in autumn where similar conditions prevail in humid forests of temperate or semitropical regions. Earth and leaf molds are easily discovered. The result of these processes is humus-soil. Thick layers are not formed because the access of air is too abundant. Should the access of air be completely cut off—as under water or layers of sand and mud—then rotting sets in, and most of the solid material is used for coal-formation. These three types of decay prevail simultaneously in a peat bog and are known collectively as humification. Bacteria and fungi play an essential role in these processes.

Besides changes of a more biological nature, purely chemical changes take place also. These changes involve the expulsion of oxygen and hydrogen as shown in the following table:

	Ratio of Carbon and Hydrogen	Ratio of Carbon and Oxygen
Cellulose	7 : 2	0 : 9
Peat	9 : 8	1 : 8
Lignite (brown coal)	12 : 2	2 : 4
Lignite (perfect)	12 : 6	3 : 6

From this table we see the progressive elimination of oxygen and hydrogen beginning with cellulose via peat and lignite, and the (relative) increase of carbon. How is oxygen eliminated? It may be eliminated from organic compounds (after many as yet unknown intermediate stages), combined with hydrogen as water (H_2O), or combined with carbon as carbon dioxide (CO_2). The formation of CO_2 is still going on in our coal mines, and its accumulation in some gassy mines may become very dangerous.

The plant body has, both relatively and absolutely, more carbon than oxygen and hydrogen; about 50-per-cent carbon constitutes the total dry weight of a tree. Carbon, hydrogen, and oxygen escape; however, more hydrogen and oxygen escape than carbon, so that, after a convenient interval, the amount of hydrogen and oxygen has decreased more than that of carbon. Hydrogen is eliminated by a process called dehydration. This latter process goes on continuously. Hydrogen may combine to water or escape as CH_4.

methane or marsh gas, as can be observed in peat and bogs.

WHERE DOES THE WATER GO?

The large amount of water present in peat or in a bog has somehow to disappear. The question is: how? Water may be present in peat in several ways. It can permeate peat as capillary water, physically bound, which can be shifted, removed by physical pressure, e.g., that of overlying sediments or by direct evaporation into the air, by infiltration into the adjacent layers of absorptive character, as sand, clay, etc. In this way about 40 per cent of the water is eliminated. With aging, due to changes in the colloids as a result of infiltrating neutral salts into the primarily acid peat substances, the swelling water is changed into capillary water. By these processes, some 10 to 20 per cent of the total amount of water is lost, thus leaving only about 40 to 50 per cent of absorbed water. Water present in this form is very difficult to expel. However, entire geological ages are available for the consummation of small effects.

These processes, in which hydrogen and carbon decrease, are called coalification. Carbonization is a process by which the material (e.g., cellulose, wood, etc.) is decomposed into simple substances and carbon. Carbon is an element which cannot be further divided without losing its carbonicity, whereas coal consists of compounds made up chiefly of carbon and hydrogen. That these processes of loss actually take place can be seen in the following table. It will easily be seen that hydrogen and oxygen, which are contained in wood fiber and other vegetable plant material, are eliminated step by step during the coalification.

	Percentage of			Calories
	Carbon	Hydrogen	Oxygen	
Wood	50	6	44	4,500
Peat	55	6	39	5,000
Lignite	70-78	5	25-17	6,000—7,000
Bituminous Coal	80-92	5-4	15-4	7,600—8,000
Anthracite	94-98	3-1	3-1	8,500—8,200

GEO-DYNAMICAL PROCESSES

Geo-dynamical processes consist principally of densification, consolidation, and devolatilization. Simultaneous with dehydration and the elimination of gases, there is a drying process. In this way, the putrefying material is reduced in volume, hardens, and takes on the geological aspect of stratified sediment. At the same time, volatile matter is lost (devolatilization). The volatile matter in peat, dried at 100° centigrade, is about 70 per cent; that of typical lignite about 55 per cent. During geological ages, as a result of pressure and probably also of heat, an almost complete expulsion of the volatile matter (oxygen, nitrogen, and hydrogen) takes place. Should the geodynamical processes cease to act upon peat, the coalification stops, as was the case with the brown coal near Moscow. The lignite found there dates from the Carboniferous era. Not being overlain by heavy sediments, it has not been pressed; whereas forests of the Tertiary age, overlain by heavy sediments, have turned into real coal. Thus age alone is not a decisive factor.

BOGHEAD COAL IN THE MAKING

Boghead coal is a coal that consists mainly of fossil algae; cannel coal consists mainly of spores. Both types are unusual in their original material but, curiously enough, we can trace the formation of the boghead coal in present times. Let us make an excursion to the Ala-Kool Gulf at the southern extremity of Lake Balkash in Turkestan. There we find an alga called *Bortyococcus*. This alga manufactures oil and thus comes to the surface. From time to time the scum of the lake is blown to the shore, where the algal masses accumulate. Soon hydrogen-sulphide fermentation sets in, the air dries the algae, and the entire mass is converted into an elastic, rubber-like substance which can easily be cut with a knife. Microscopic studies and chemical analyses have shown that Balkashite can be assumed to be the beginning of boghead coal. From studies of Coorongite (named after the river Coorong, South Australia) which is formed from the alga *Elaeophyton*, the conclusion can be drawn that Coorongite is the peat stage of boghead coal.

COAL PETROGRAPHY

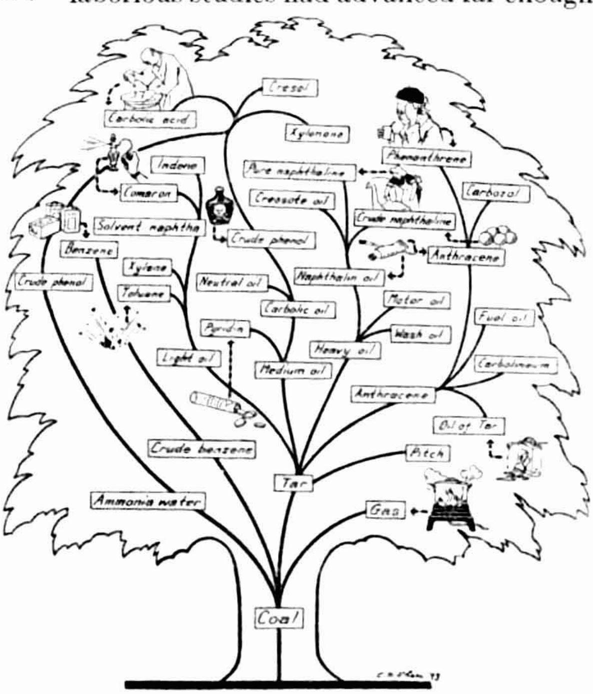
The microscopic study of the physical composition of coal is called petrography. Most of the coal which we use in our stoves is banded coal. If we select a lump we can easily classify it into the following groups. There are narrow layers of glossy material, more or less homogeneous, appearing as bands on the surface. These layers, like glass, break easily into cubes with a conchoidal (mussel-like) fracture. Hence the name vitrain. Another kind is dark brown in color, smooth and compact; its broken surface is never even. A large amount of pollen grains or spores are found in this type, called durain. In still another type of coal (all three types may be found in the same lump) a typical fibrous structure can be observed with the naked eye. This type has been called mineral charcoal, fusain. The anatomy of these wood pieces can be easily recognized.

There is some uncertainty and hence some dispute over the origin of fusain. Forest fires may cause layers of charcoal 5 centimeters deep; but to explain a layer of fusain 8 meters in thickness by forest fires does not seem convincing. Besides, megaspores are found in these layers, and they show no sign of having endured heat. The problem is not yet solved. Recent laboratory studies have indicated that woody material may change into fusain at normal temperature by anaerobic bacterial decomposition in a basic medium.

COAL IN THE TWENTIETH CENTURY

For industrial purposes, waterfalls (white coal) supply about 10 per cent of the power, oil and gas about 37.7 per cent, and coal about 52.2 per cent. This strikingly shows the vital importance of coal for a country whether in peace or at war. Of the same, if not greater, importance are the by-products of coal industries. When coke and gas are manufactured by the dry distillation of coal at 900 to 1200° centigrade, some by-products are inevitable. Among these is coal tar. Black and thick in appearance, coal tar is for many branches of our industries of greater importance than the coal itself. In the hands of the ever-progressing chemical industry it has become the source of an unimaginable variety of valuable material (see illustration). Usually we say that a gold mine is the symbol of the greatest potential value; but this figure of speech is utterly inadequate to convey the enormous wealth of usefulness which the earnest labor of the chemical industry has created from coal tar.

Bergius and his co-workers in the production of benzene experimented with and discarded 20,000 different catalysts in an attempt to discover the most suitable substance to promote chemical reaction and which would not be destroyed by acids commonly found in coal, and which would be at the same time economical. And when, after six years of ingeniously arranged experiments, the laborious studies had advanced far enough



to think of putting the laboratory experiments on a commercial basis, the price of gasoline had dropped from 18 cents a gallon to 3.6 cents a gallon in 1931.

There is still a long array of substances produced which await the skill of a competent explorer to be turned into a substance long needed by mankind. The hues of the rainbow are nothing when compared to the range of colors and shades of our synthetic dyes. Modern medicine copes with many diseases through the beneficent help of synthetic drugs, which owe their ultimate origin to coal tar. The perfumes of nature's flowers are less varied than those produced in lavish quantity from this evil-smelling, disagreeable raw material.

CONCLUSION

If such an interrelation exists between perfumes and drugs, it is easy even for the layman to understand that a dyestuff factory does not require many changes in raw material and methods to produce potent synthetic drugs or vice versa; or to readjust itself to the manufacture of explosives or poison gas, or medicine, or synthetic rubber. Industries of this type are estimated, protected, and subsidized by the governments, and rightly so since they are a very important national asset. If we consider the gigantic development of the industries which work on coal, coal tar, and their byproducts, we are justified in speaking of a new era in organic chemical industries.

In a bird's-eye view we have surveyed the tremendous variety of produced substances: compounds for pharmaceutical use, for prevention and suppression of diseases and illnesses, compounds used as antiseptics and antipyretics, as hypnotics and anesthetics, etc. We might exhaust the entire gamut of superlatives in the description of the immense variety of useful products which we enjoy in a comfortably heated room, products creating beauty and value—and all synthesized from disagreeable, common coal tar. Riches, which do not lie in finance or economics but in their significance in human affairs, riches which were laid down aeons ago unnoticed by any human eye, riches which are bursting and bristling with potential discoveries, are enclosed in petrified sunlight, the inconspicuous black coal.

More Worries For The FBI

In order to prevent acts of sabotage, all war-essential plants in the United States have been ordered to exert strict supervision on all persons entering the factory area. Every person entitled to admittance must carry an identification card with his photograph on it. Not so long ago, the FBI, the American secret police, made a check-up on how these orders were being carried out. This check-up frequently brought to light an appalling negligence.

One of the agents managed to enter several plants with an identification card showing the excellent portrait of a gorilla. It was not until he visited the sixth plant that the lack of resemblance struck the gateman. Another agent went around questioning workmen and office employees on all kinds of war-essential manufacturing secrets. He brought back a whole notebook full of information which would have been invaluable to foreign spies. A third agent happened quite by chance to discover an old sewer of more than ten feet in diameter under an ammunition plant. The entrance to this sewer was some distance from the factory area and, in addition, the sewer had manholes every few yards through which a whole army of saboteurs might have crawled in and out of the ammunition plant.